OFFPRINTS FROM MARINE INVERTEBRATE FISHERIES: THEIR ASSESSMENT AND MANAGEMENT
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4 APPROACHES TO RESEARCH AND MANAGEMENT OF U.S. FISHERIES FOR PENAEID SHRIMP IN THE GULF OF MEXICO

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1. INTRODUCTION

Trawl fisheries of the U.S. southeast region harvest two major faunal groups: shrimp and bottom fish. The shrimp fishery is considered to be the most valuable fishery in the United States. In 1984, the Gulf and Atlantic coastal states produced 124,000 metric tons (274 million lb) of whole shrimp valued at more than $449 million. Historically, the Gulf of Mexico has been the major U.S. production area for shrimp and accounts for approximately 80% of the total value of shrimp landed in the United States. Shrimp production in the Gulf has fluctuated between 61,000 metric tons (134 million lb) in 1961 and 121,000 tons (266 million lb) in 1977. The directed shrimp fishery in the Gulf of Mexico harvests brown shrimp, *Penaeus aztecus* (the dominant species, accounting for more than 50% of the total production), white shrimp, *P. setiferus*, and pink shrimp, *P. duorarum* (which account for 25–35% and 15–20%, respectively). This shrimp fishery also incidentally catches and discards up to 900,000 metric tons of bottom fish annually (Klima 1).

Major emphasis on shrimp research was initiated in the late 1950s by the Gulf coastal states and by the Galveston Laboratory of the Bureau of Commercial Fisheries (now the National Marine Fisheries Service, NMFS) to explore shrimp resources and to define basic biological parameters (Temple 2; Caillouet and Baxter 3). Since that time, the Gulf states have continued a strong research role in providing scientific information for management of the shrimp resources. Each state was funded by its legislature and undertook programs that provided appropriate information for management. The federal government provided biological data, catch and fishing effort, and some economic data to the Gulf states. In the early 1960s, intensive surveys by the Bureau of Commercial Fisheries throughout the Gulf of Mexico provided basic information on the biology, spawning cycle, maturation, growth, and life history of the major shrimp stocks. These findings were summarized by Lindner and Cook (4, 5) and Costello and Allen (6). In the late 1960s, the Bureau of Commercial Fisheries significantly decreased its emphasis on shrimp research.

In 1976, the United States Congress enacted The Fishery Conservation and Management Act of 1976 (Magnuson Act), extending U.S. jurisdiction from the edge of state territorial waters to 200 miles offshore and creating regional management councils that have responsibility for developing management plans for all U.S. coastal ocean resources. As a result of this action, emphasis was again placed on providing scientific information for the management of shrimp resources.

This paper summarizes results of current shrimp management, and research programs, including estuarine research programs in the U.S. Gulf of Mexico.

2. BACKGROUND

2.1. The Fishery

The distribution and relative abundance of white, brown, and pink shrimp have been described by Osborn et al. (7) and are depicted in Figures 1–3. The brown shrimp population is found throughout the northern and western Gulf of Mexico, with the center of abundance off Texas. White and pink shrimp are also located throughout the northern Gulf with the center of abundance of white shrimp off Louisiana and that of pink shrimp off southern Florida, with highest concentrations

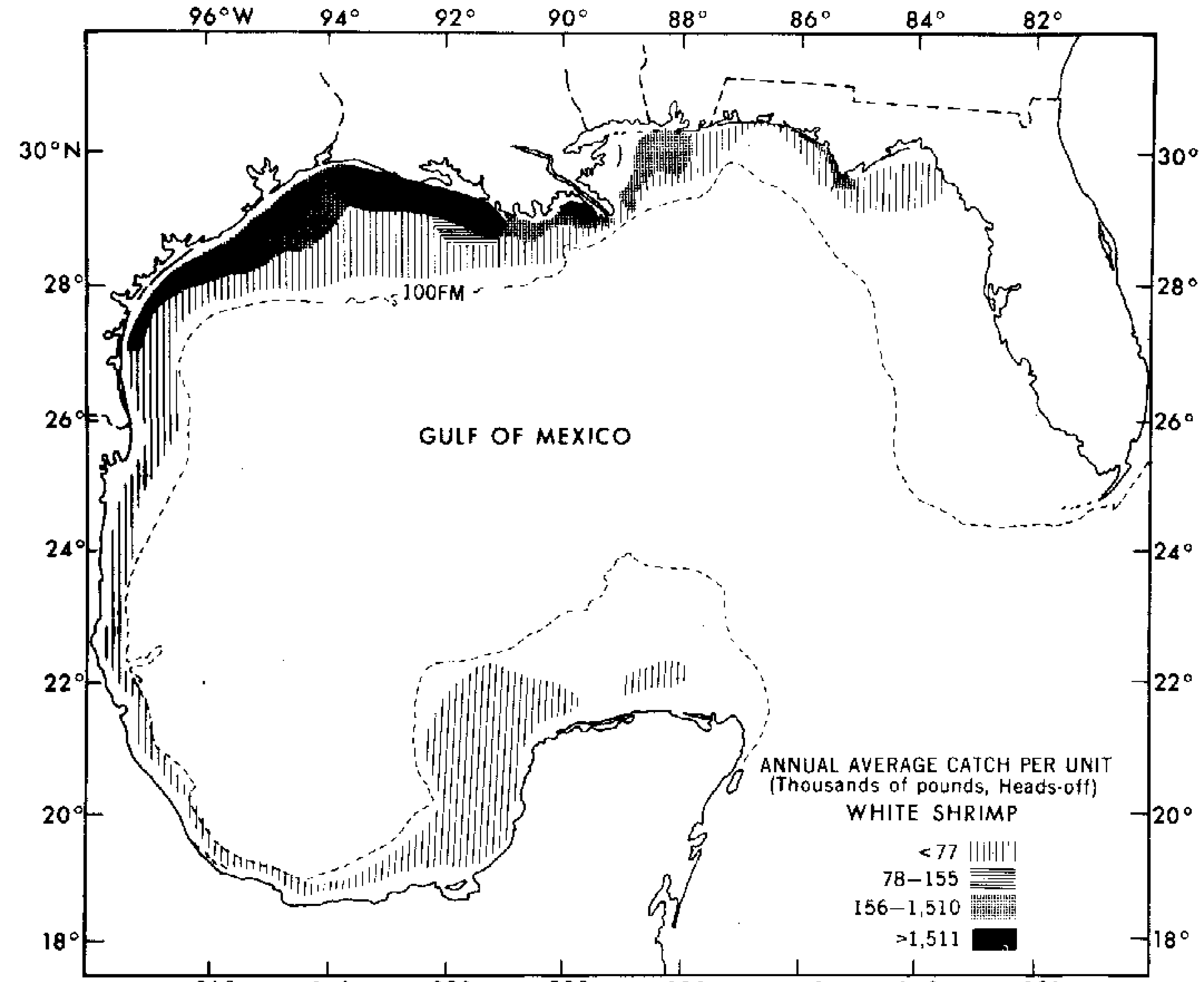

Figure 1. Distribution of catch per unit (thousands of pounds) of white shrimp in the Gulf of Mexico.

around the Dry Tortugas area. White shrimp are believed to have a continuous distribution throughout the northern half of the Gulf and into Mexico. Lindner and Anderson (8) found tagged white shrimp moved across the United States–Mexico border. There appear to be two separate stocks of pink shrimp, one on the Campeche Bank off Mexico and the other off south Florida on the Tortugas and Sanibel grounds. Sheridan et al. (9) and Klima et al. (10) have shown that both brown and pink shrimp stocks freely transit the United States–Mexico border.

Biological information and crude landing statistics have been collected since the turn of the century in the Gulf of Mexico. After World War II, the shrimp fisheries of the Gulf expanded rapidly with the development of the Tortugas fishery off south Florida and the brown shrimp fishery off Texas. Prior to that time, the fishery exclusively pursued white shrimp during daylight hours. Both the pink and brown shrimp fisheries were nocturnal, and production increased rapidly from the early 1950s to the present. The development of more powerful vessels, fishing gear, and electronics allowed the fleet to expand to offshore areas throughout the Gulf of Mexico.

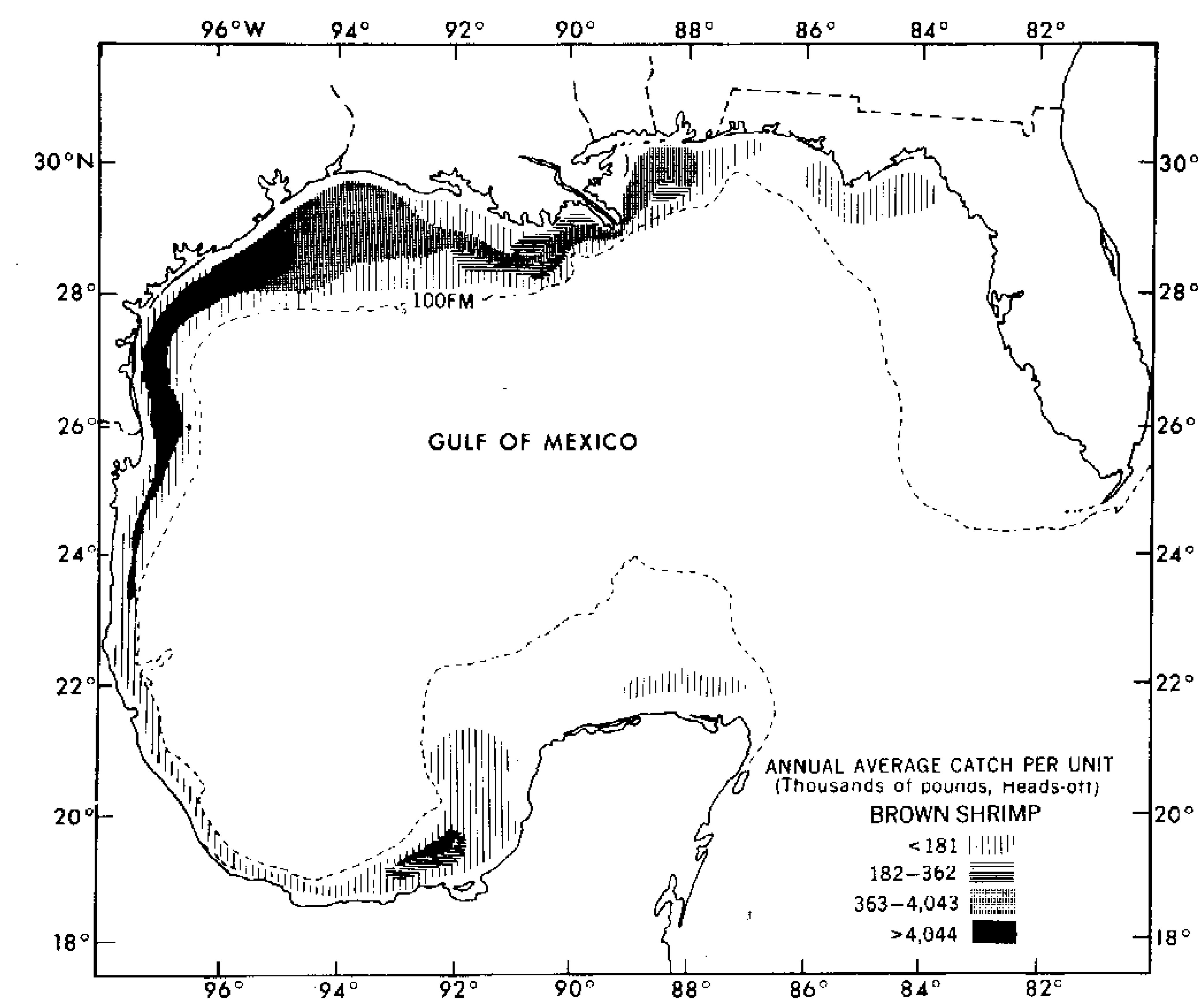

Figure 2. Distribution of catch per unit (thousands of pounds) of brown shrimp in the Gulf of Mexico.

Brown shrimp landings and directed effort have doubled since 1960, despite frequent short-term fluctuations (Fig. 4). Catch-per-unit effort (CPUE) has shown considerable and frequent fluctuations but no increasing or decreasing trend. The average size of captured brown shrimp (Fig. 5) has decreased markedly since 1960 and appears to be inversely related to the increase in effort (Nichols 11). Caillouet et al. (12) likewise have shown a decrease in the average size of brown shrimp in the central Gulf, apparently due to high fishing effort exerted on juveniles in the estuarine areas of Louisiana. In contrast, a relatively constant size off the coast of Texas may be a result of management practices where few immature shrimp have been taken through 1979. This trend is changing as Texas inshore fisheries for brown shrimp began increasing in 1979 (Klima et al. 13).

White shrimp landings have fluctuated appreciably since 1960 (Fig. 6). Peak catches during good years have been relatively constant, but the catches in poor years have been increasing (Nichols 11). The directed effort for white shrimp has more than doubled despite substantial short-term fluctuations. On the other hand, CPUE has shown a long-term decline of 25%, with short-term fluctuations of much

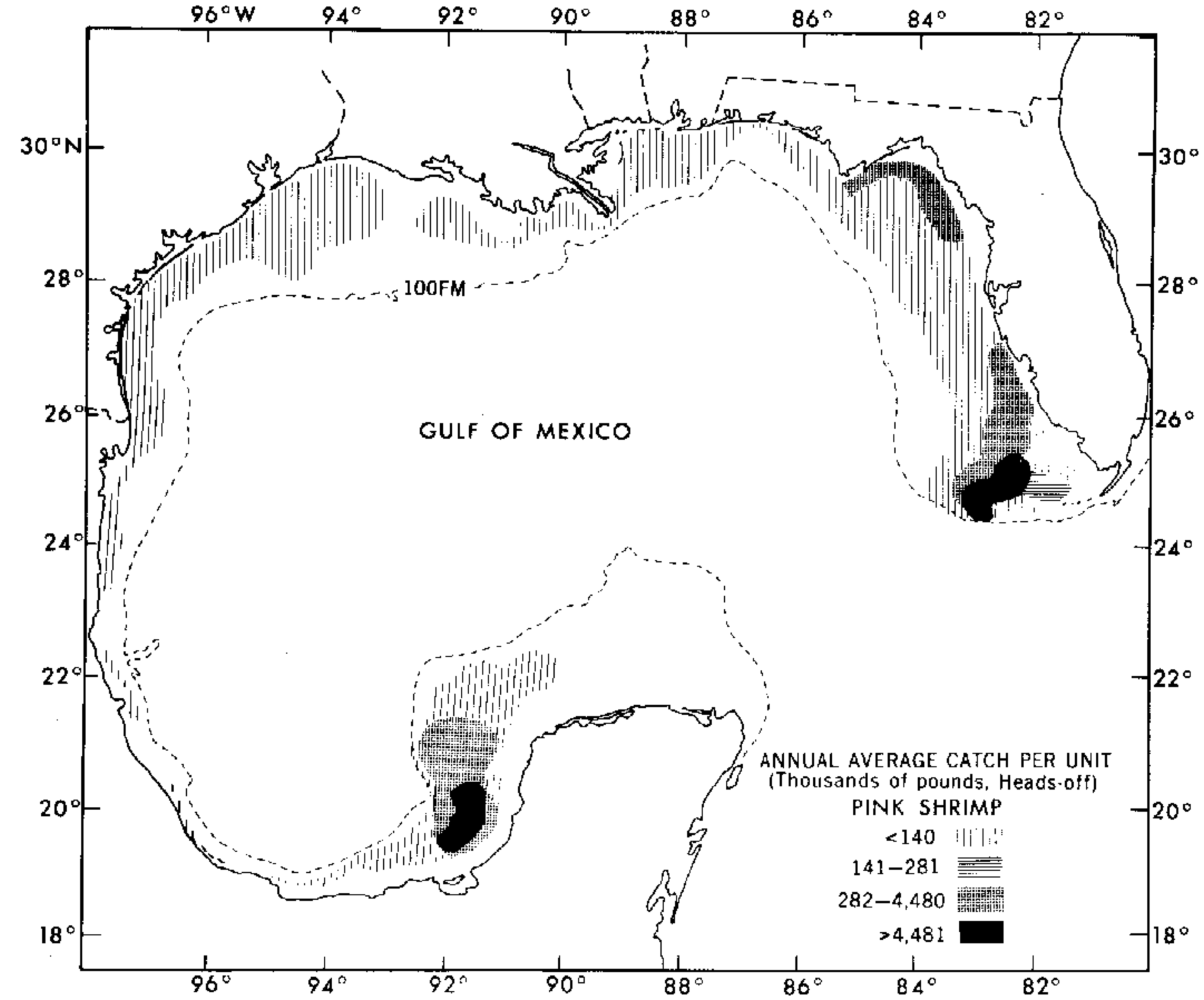

Figure 3. Distribution of catch per unit (thousands of pounds) of pink shrimp in the Gulf of Mexico.

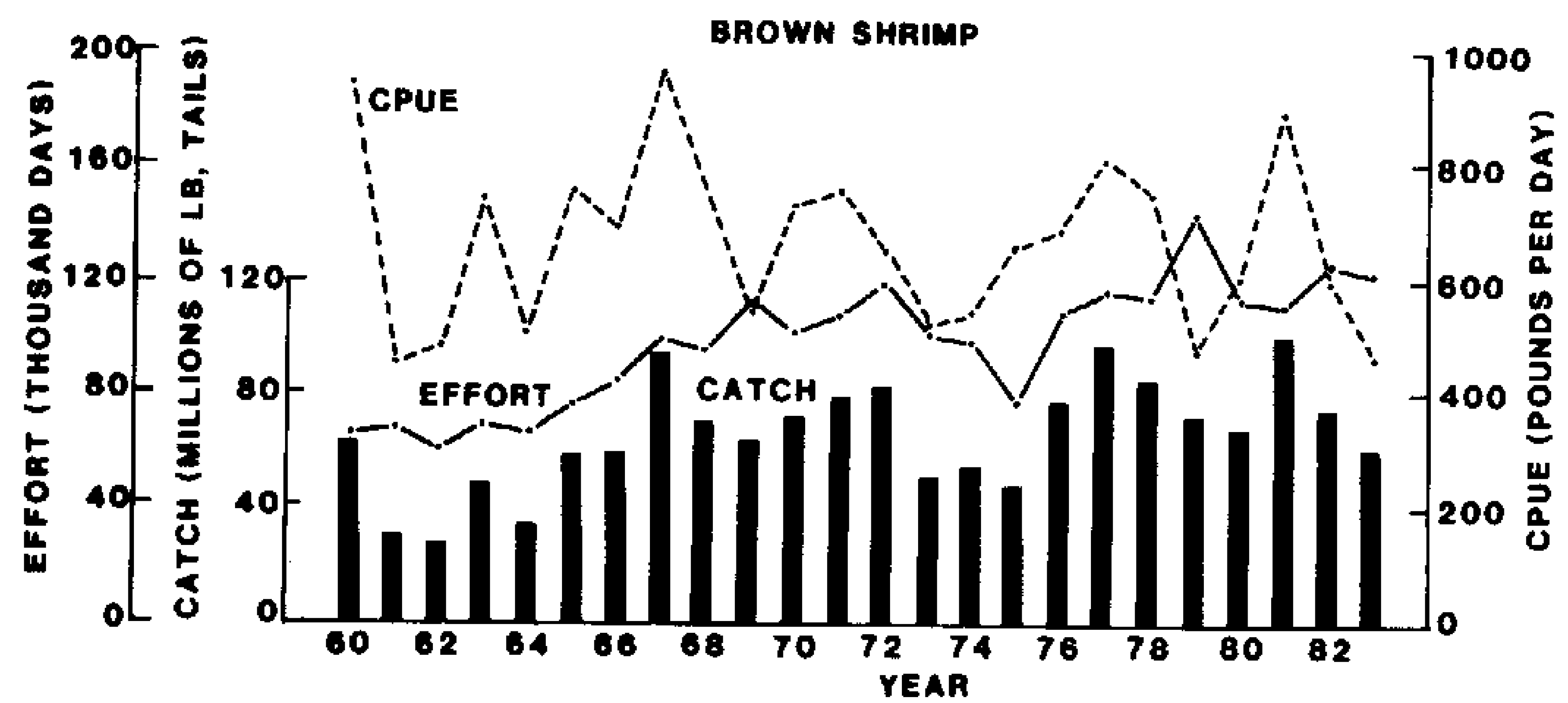

Figure 4. Brown shrimp reported annual landings, directed effort, and average catch per unit effort.

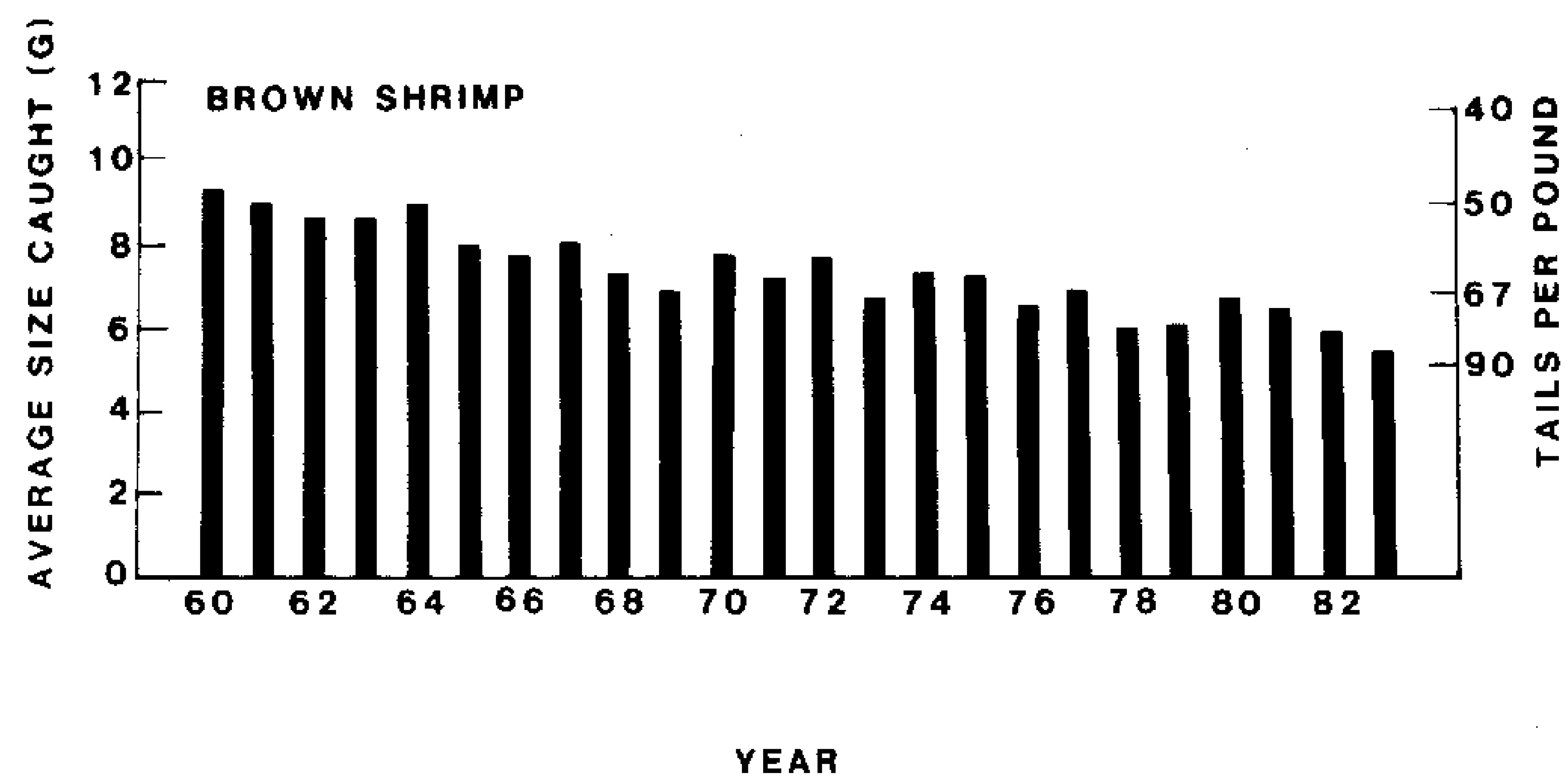

Figure 5. Annual average size of brown shrimp landed.

greater magnitude. The average size of captured white shrimp has declined over the 24-yr period (Fig. 7), but the decline is not as great as the decline observed with brown shrimp (Nichols 11).

Pink shrimp landings have been relatively stable since 1960 with appreciable fluctuations and no apparent trend (Fig. 8) (Klima et al. 14). Fluctuations are appreciably smaller than observed for either the brown or white shrimp stocks. Directed effort appears to fluctuate around two levels with a transition in the early 1970s to appreciably higher levels of effort from 1973 to the present. CPUE appears

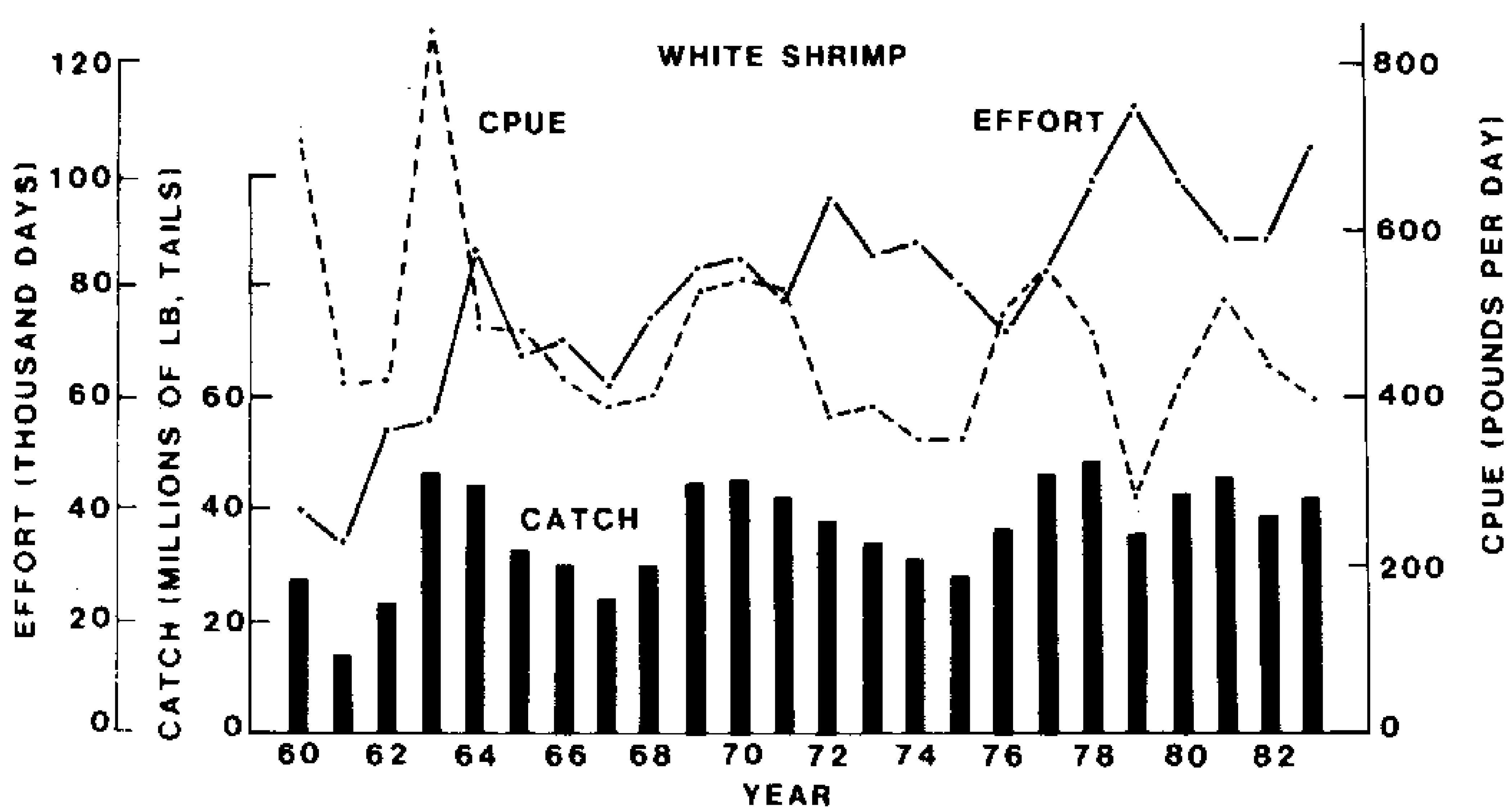

Figure 6. White shrimp reported annual landings, directed effort, and average catch per unit effort.

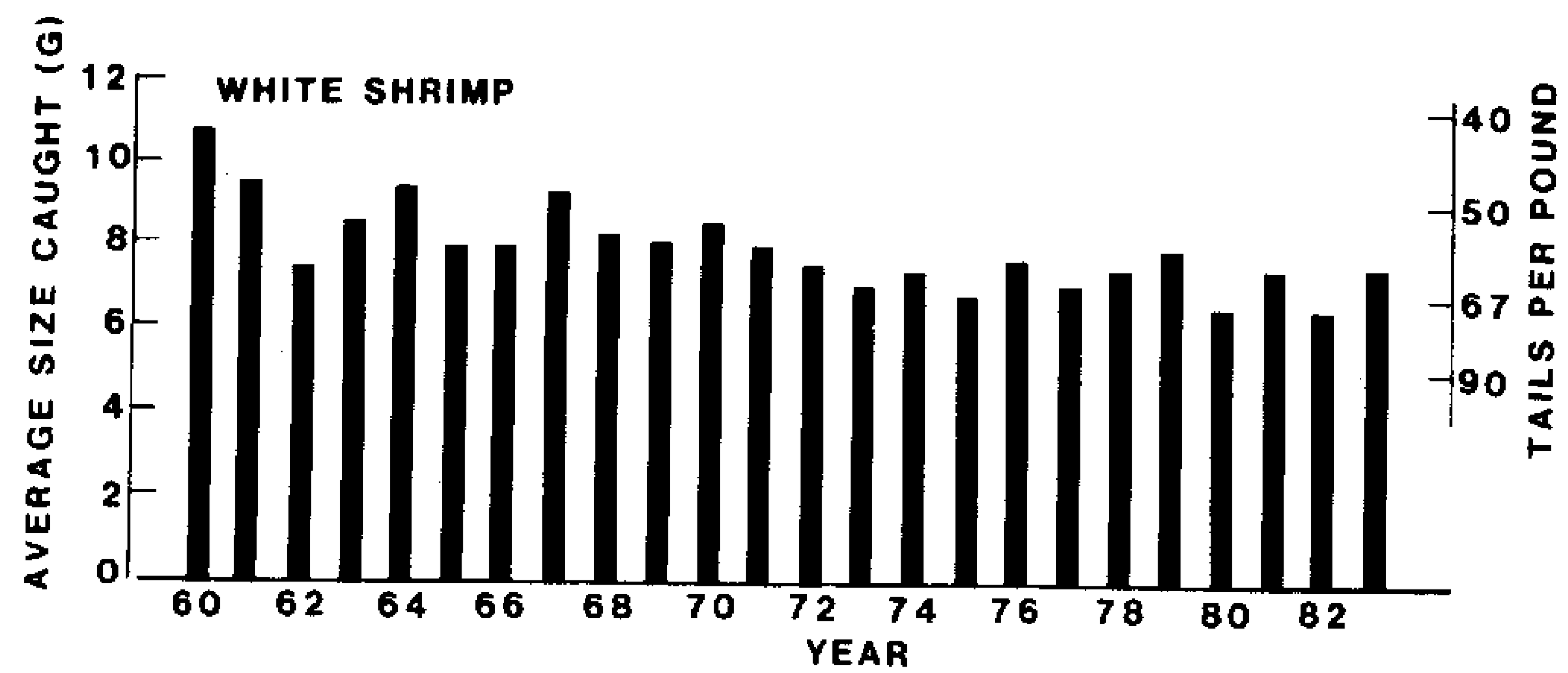

Figure 7. Annual average size of white shrimp landed.

stable throughout the period with no apparent trend. Likewise, the average size of shrimp (Fig. 9) has fluctuated considerably with no continuing trend over the 24-yr time frame (Nichols 11).

2.2. Biological Data Base

The biological data base for shrimp has been accumulating for the past 40 yr. The initial work reported by Lindner and Anderson (8) set the stage for understanding

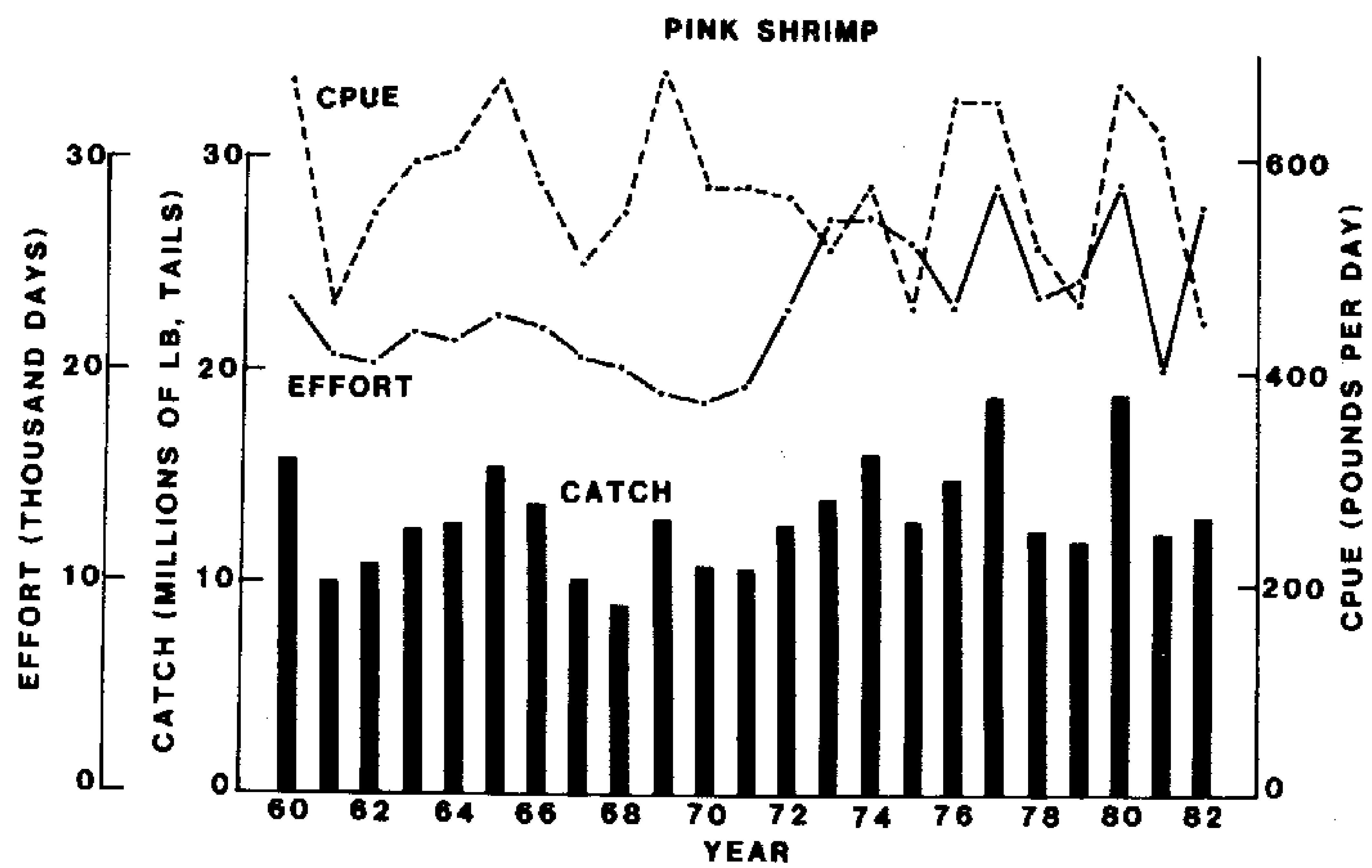

Figure 8. Pink shrimp reported annual landings, directed effort, and average catch per unit effort.

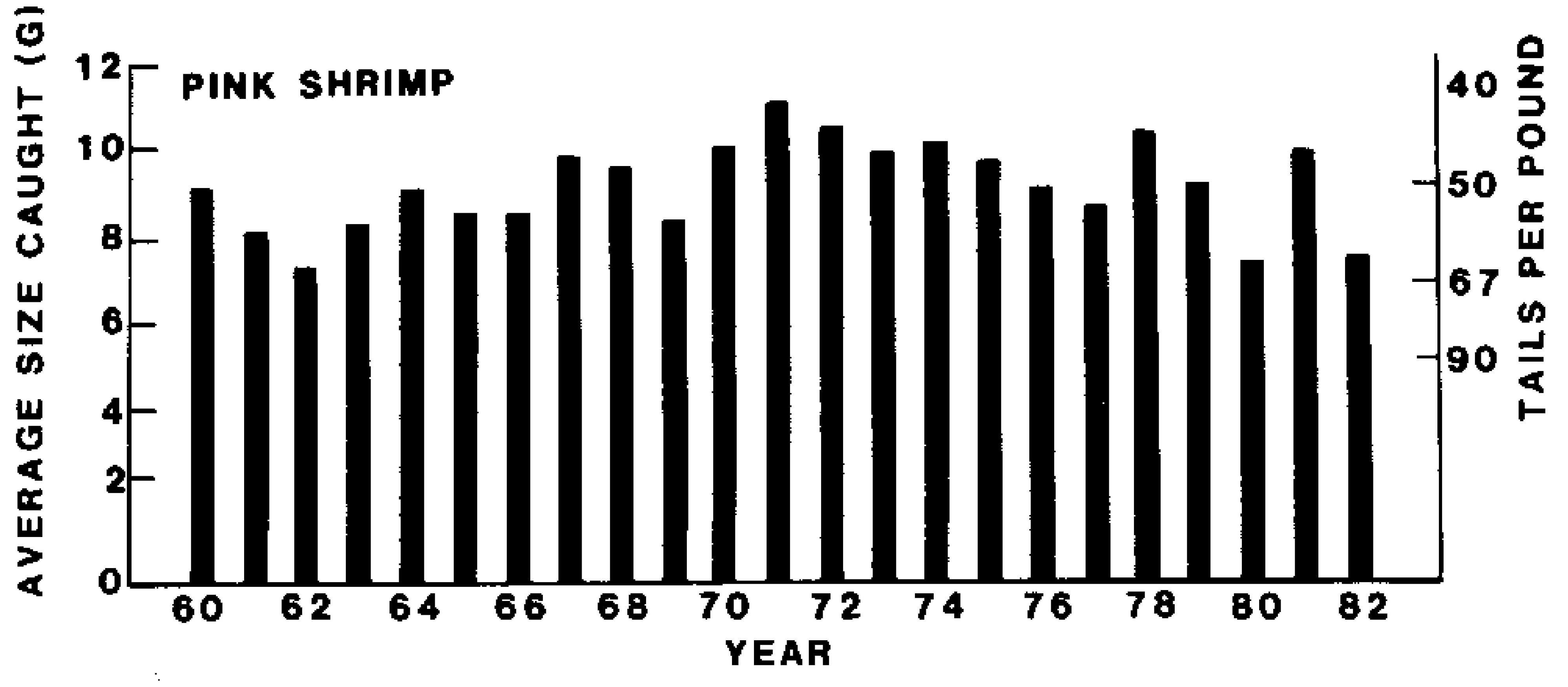

Figure 9. Annual average size of pink shrimp landed.

migration and growth of the white shrimp throughout the northern Gulf and south Atlantic. Recently workers have greatly expanded information on growth, mortality, and other important biological aspects. Some important findings on mortality and growth used to manage shrimp fisheries are reported by Klima et al. (15), Parrack (16), Iversen and Jones (17), Costello and Allen (6), Kutkhun (18), Berry (19, 20), Lindner (21), and Neal (22), and thoroughly reviewed by Christmas and Etzold (23). Growth studies conducted by NMFS, summarized by Klima (24) and reported by Phares (25), show that growth of shrimp is seasonal and is positively related to temperature. Nichols (11) updated the assessment of brown, white, and pink shrimp stocks in the Gulf of Mexico and put into focus information available for management of the shrimp stocks of this area. Nichols (11) not only updates most of the biological information but adds new information on age, growth, and estimates of mortality for these important stocks. Recognizing that estimation of natural mortality (M) may be the single most difficult technical problem in fisheries science, he used two variations of fishing effort to obtain estimates of total mortality. Nichols provided the best estimates for brown shrimp of M as 0.27–0.31/month; best estimates of M for white shrimp were 0.20–0.22/month. He believes that M for adults for both species is between 0.20 and 0.35/month but he has been unable to narrow this range further. Nichols (26) used such data to develop models for the Gulf of Mexico Fishery Management Council related to the Texas Closure (Nichols 27; Poffenberger 28) as well as to provide information on the impact of the Tortugas Sanctuary area on pink shrimp (Nichols 26).

2.3. Management

By the late 1940s, the Gulf coastal states individually expressed concern over the economic welfare of the shrimp fisheries and began implementing state regulations to conserve and manage fishery resources. General objectives of the present state

management systems have been to protect the resources and maximize catch among the various user groups. Regulations of the size of harvestable shrimp have been implemented by the various states. Most states regulate the harvestable size of shrimp by opening and closing seasons in state waters and, to some degree, by the restriction of various gears. A summary and comparison of the Gulf states regulations is presented in Table 1. With the implementation of the Magnuson Act in 1976 the Gulf of Mexico Fishery Management Council (GMFMC), one of eight regional management councils, completed a plan in 1981 for managing the shrimp fisheries in the Fishery Conservation Zone (FCZ) (i.e., federal waters that extend from the Territorial Sea out to 200 miles).

Management measures are based on assumptions that no recruitment overfishing occurs, that the stock is a single year class, and that there is a need to protect small shrimp, because growth overfishing is a significant problem in most of the coastal states. Rothschild and Brunenmeister (29) summarized the council's scientific view of the shrimp stocks in the Gulf as follows: (1) there is no demonstrable relationship between stock size and recruitment levels for Gulf of Mexico shrimp stocks; (2) recruitment overfishing of shrimp stocks is impossible; (3) there should be no constraints on the quantity of shrimp taken each year; (4) the environment, especially temperature and salinity and not stock size, controls the success of recruitment; and (5) surplus production models are inadequate for providing guidance on the relationship between stock production and the amount of fishing. These authors discuss the council's views and in general provide information that negates these points. Present management regulations are based more or less on these assumptions.

It is not the intent of this paper to review these concepts except to concur with Rothschild and Brunenmeister (29) that in fact, production models do serve a useful purpose for management, that recruitment overfishing is a distinct possibility with Gulf of Mexico shrimp stocks, and that care should be taken in management of these stocks so that recruitment overfishing does not occur.

The GMFMC identified multiple management problems, and adopted a goal and objectives to resolve these problems:

Goal: To manage the shrimp fishery of the United States waters of the Gulf of Mexico in order to attain the greatest overall benefit to the nation with particular reference to food production and recreational opportunities on the basis of the maximum sustainable yield as modified by relevant economic, social, or ecological factors.

Objectives:

1. Optimize the yield from shrimp recruited to the fishery.
2. Encourage habitat protection measures to prevent undue loss of shrimp habitat.
3. Coordinate the development of shrimp management measures by the

TABLE 1 Comparison of Gulf Shrimp Regulations[a,b,c]

	Florida	Alabama	Mississippi	Louisiana	Texas	Fishery Conservation Zone Plan (Federal Waters)
Shrimp size in outside waters	47 w, 70 h [1,2,3]	68 w[2,3,4]	68 w	100 w (except during spring season)[2]	None	None
Shrimp size in inside waters	47 w, 70 h	68 w[2,3,4]	68 w[1,2,3]	100 w (except during spring season)[2]	50 w, 65 h[1,2,3] Aug. 15 to Oct. 31	None
Closed Gulf seasons	Stone crab areas[4] Tortugas Sanctuary all year	None	May 1–1st Wed. in June in sound and 3 mi out	Jan. 15–March 15 w/15-day flex NTE 60 days[2]	June 1–July 15 ×4 fathoms during day for white shrimp[3] To 7 fathoms Dec. 16–Feb. 1[3] Night all year[3]	June 1–July 15 Texas FCZ[3] Stone crab areas[4] Tortugas Sanctuary all year
Gear restrictions in outside waters	Trawl size limits[1]	None	None	NTE 4 trawls 1 Try NTE 16 ft Mesh NLT 5/8 in. Bar ($1\frac{1}{4}$ in. Stretched)[2,3]	NLT 3/4 in. in stretched mesh[2,3] Bay net inside 4 fathoms	None

[a]Provided by T. Leary, Gulf of Mexico Fishery Management Council.

[b]Key:

w = number of whole shrimp/lb.

h = number of headless shrimp/lb.

NTE = not to exceed.

NLT = not less than.

w/15 day flex = flexible opening and closing ±15 days.

[c]Objective:

[1]To protect small pink shrimp from premature harvest.
[2]To protect small white shrimp from premature harvest.
[3]To protect small brown shrimp from premature harvest.
[4]To prevent gear conflict.

GMFMC with shrimp management programs of the several states, where feasible.
4. Promote consistency with the Endangered Species Act and the Marine Mammal Protection Act.
5. Minimize the incidental capture of finfish by shrimpers when appropriate.
6. Minimize conflicts between shrimp and stone crab fishermen.
7. Minimize adverse effects of underwater obstructions to shrimp trawling.
8. Provide for a statistical reporting system.

The GMFMC adopted, and the NMFS implemented, the following management measures to achieve the desired objectives:

1. Establish the cooperative permanent closure with the state of Florida and the U.S. Department of Commerce off south Florida to protect small pink shrimp until they generally reach a size larger than 68 tails/lb.
2. Establish a cooperative closure of the territorial sea of Texas and the adjacent U.S. FCZ with the state of Texas and the U.S. Department of Commerce during the time when a substantial portion of the brown shrimp in these waters are less than a count of 65 tails/lb.

3. SANCTUARIES AND CLOSURES

3.1. Tortugas Shrimp Sanctuary

The Gulf of Mexico Shrimp Fishery Management Plan established an area commonly known as the Tortugas Sanctuary off south Florida (Fig. 10) and prohibited all trawling activity within that area between May 15, 1981 and April 15, 1983. This regulation was founded on scientific data indicating that the sanctuary is a nursery area for the Tortugas stocks of pink shrimp and that recruitment to the offshore fishery depends on the sanctuary. Lindner (21), Berry (20), and Nichols (26), utilizing growth and mortality data, indicated that the yield of pink shrimp would be greater if harvest was delayed until shrimp were larger than the minimum legal size (69-count*) for landing shrimp in Florida.

The Gulf of Mexico Fishery Management Council's goal in establishing the sanctuary was to protect small, undersized shrimp from fishing. Furthermore, it was assumed that small shrimp were found mainly inside the sanctuary line and that shrimp outside the sanctuary were of legal size or larger. The establishment of a permanent sanctuary was estimated to increase annual yield by about 1 million lb. The "toe" area of the boot-shaped sanctuary was reopened to trawling from April 1983 until August 15, 1984 because of pressure by the shrimp industry, which claimed they could not survive economically without fishing the "toe" of

*The number of shrimp tails that constitutes 1 lb.

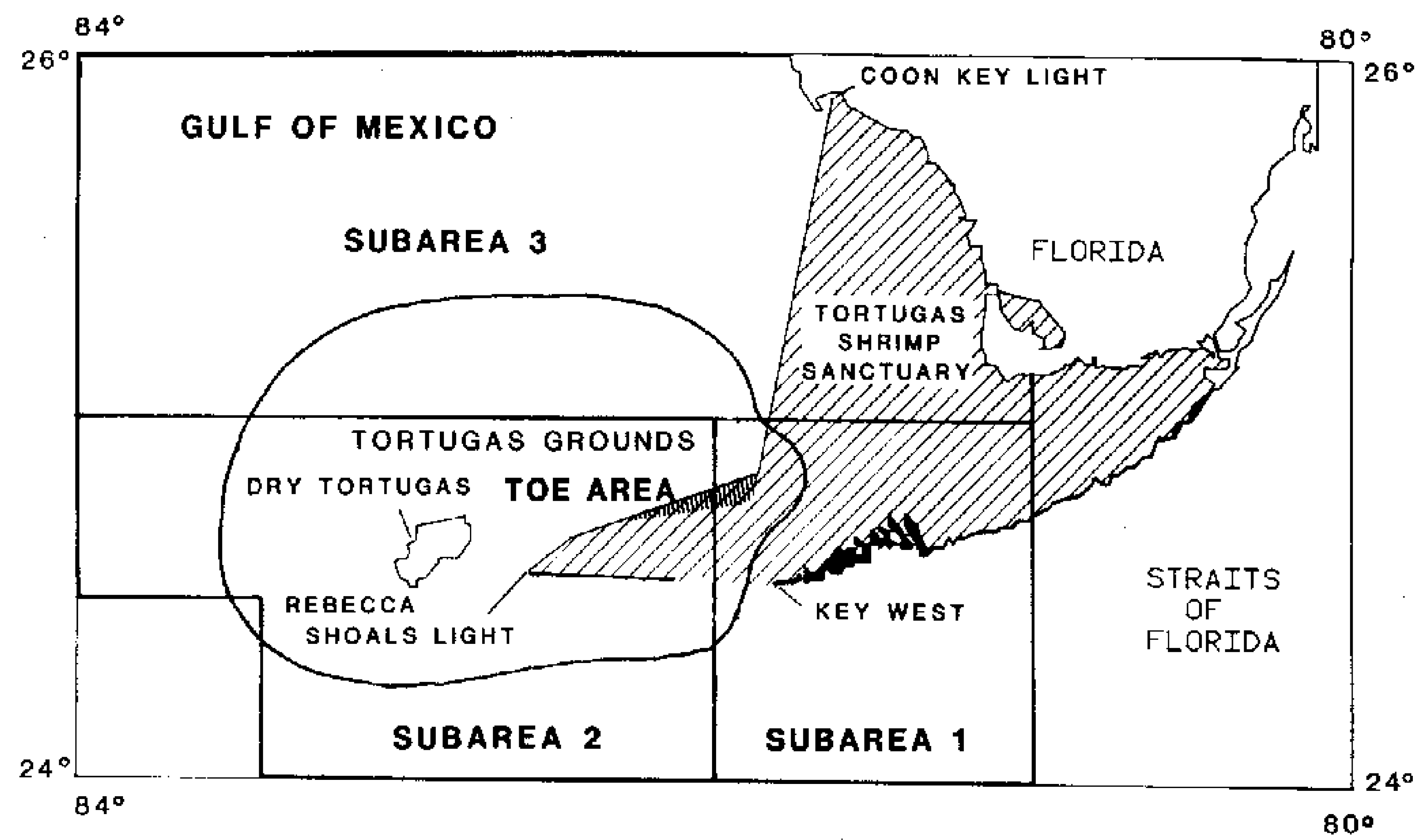

Figure 10. Chart of Dry Tortugas fishery grounds and statistical subareas.

the sanctuary. The prohibition on trawling in the "toe" of the sanctuary was reestablished on August 16, 1984.

The Tortugas fishery has been very stable, with average annual production of about 9.9 million lb that does not fluctuate greatly from year to year. The fishery is bounded by non-trawlable bottoms of loggerhead sponges and coral reefs, where pink shrimp are protected from trawling even though they may be present in high concentrations. The large area of untrawlable bottom surrounding the fishery grounds may explain why this fishery has been so stable since 1960.

Historically, the primary recruitment of small shrimp onto the Tortugas grounds occurs between September and November, although spring recruitment is occasionally strong. In March and April 1981 (prior to the closure of the sanctuary) there was good recruitment of small shrimp onto the Tortugas grounds (Klima and Patella 30; Klima et al. 14). That recruitment continued into the closure period (May 1981) and sustained the fishery through the remainder of 1981. The 1981 catch amounted to 10.2 million lb. However, there was no strong recruitment onto the Tortugas grounds again until March through May 1983. Consequently, the fishery from May 1982 through April 1983 appeared to collapse to an all-time low of about 7 million lb of shrimp.

From April 1983 to August 1984, a portion of the "toe of the boot" area of the sanctuary was opened to fishing and the fleet concentrated its effort on extremely small and abundant shrimp. This was reflected in an increase of the average size count of shrimp landed as well as landings of more than 1 million lb/month (Fig. 11; Klima and Patella 30). Recruitment was poor in the fall of 1983. Above average recruitment was again observed in both April and May 1984. This peak spring 1984 recruitment was again rapidly harvested because the "toe area" was open to fishing, with a catch of more than 1 million lb/month of extremely small shrimp

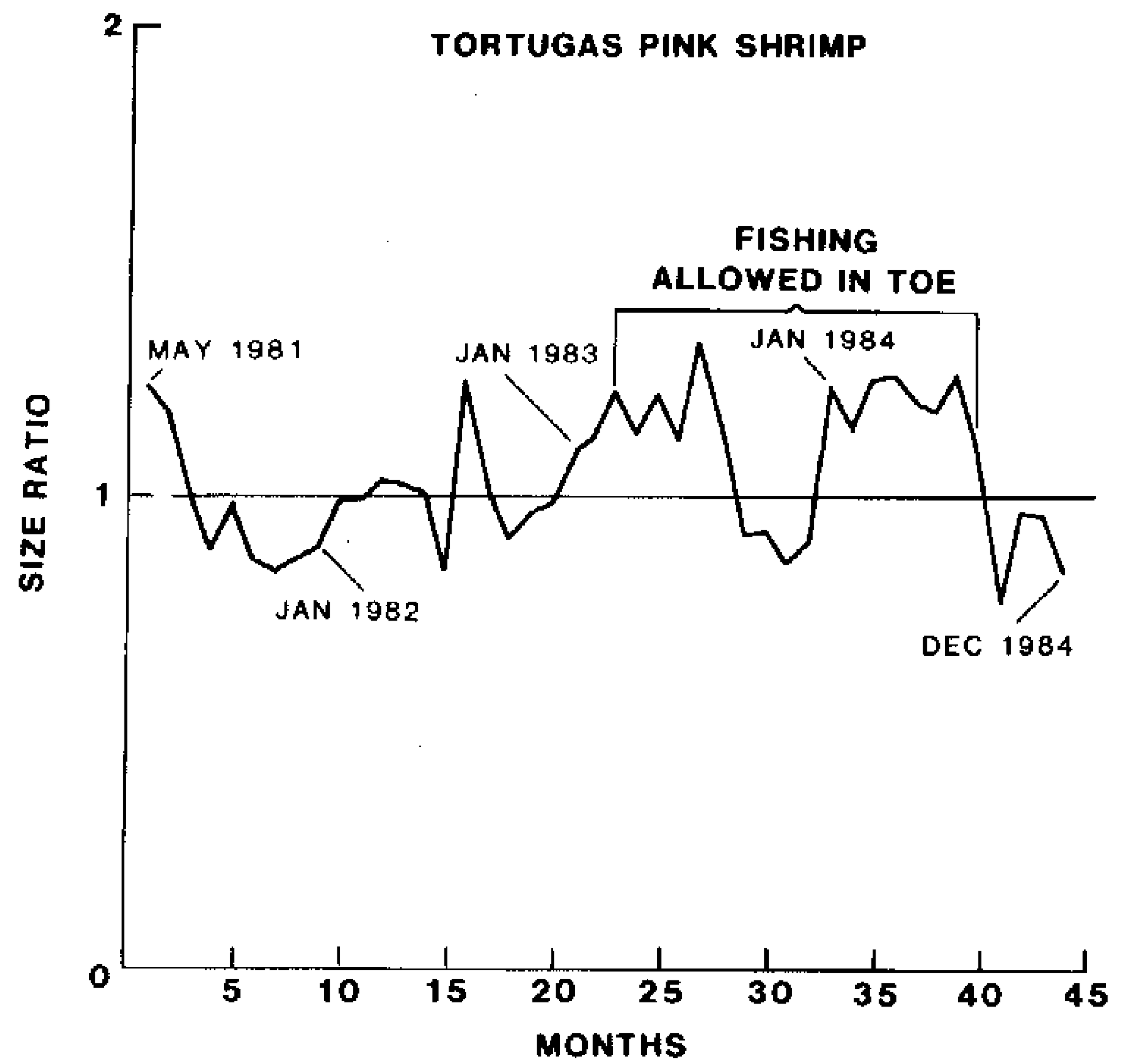

Figure 11. Ratios of monthly mean number of pink shrimp per pound from May 1981 to December 1984 to monthly mean number of pink shrimp per pound from 1960 to 1979.

(Fig. 11). After the closure of the "toe area" to fishing in August 1984, the average size landed increased above that of the monthly historical mean.

The fishery from May 1982 through April 1984 produced an all-time low of about 7 million lb for the biological years 1982 and 1983. Production from May to December 1984 was relatively low with a total yield of only 3.0 million lb. The only exceptional month was December 1984, in which 1.94 million lb of large shrimp (33 count) was landed.

The high production of large shrimp during December was probably due to the spring recruitment of shrimp that did not move onto the fishing grounds in August and September, but stayed either in the loggerhead sponge area north of the fishery or in the sanctuary. This stock apparently moved onto the grounds in November–December 1984 (Klima and Patella 30). The authors hypothesize that the shrimp stock was basically protected from the fishery either by the sanctuary or by the loggerhead sponges. They point out that shrimp with a count of 150–200/lb would take about 6 months to reach a size of 20-count and therefore shrimp of this size recruited to the sanctuary area from the Florida Everglades during May would take about 6 months before they reach a size of 20-count shrimp (Berry 19). They further point out the December 1984 fishery was basically concentrated in the extreme northern and northeastern part of the Tortugas fishery.

Klima and Patella (30) state that the production of the fishery from 1981 to 1984 was set by the amount of recruitment and the opening and closing of fishing in the "toe area." With good recruitment in the March through April 1981 period, the stage was set for a good fishery, whereas the lack of recruitment in 1982 and 1983 resulted in devastatingly low production. Good recruitment in the spring of 1983 coincided with the opening of the "toe area" to fishing, which they believed reduced the total yield because of the excessive harvest of small shrimp. These authors conclude that the sanctuary and the "toe area" contain large concentrations of small shrimp and prohibition of trawling in these areas should increase yield to the fishery.

3.2. Texas Closure

The Gulf of Mexico Shrimp Fishery Management Plan (FMP), prepared by the Gulf of Mexico Fishery Management Council and implemented in 1981, seasonally regulates the fishing for brown shrimp in the FCZ off the coast of Texas. This regulation has prohibited shrimp fishing in the FCZ each year since 1981 from late May to mid-July. Concurrently, the state of Texas regulations ban shrimp fishing in its territorial sea, except for the white shrimp fishery inside 4 fathoms. Thus all fishing for brown shrimp was prohibited during these periods in waters along the Texas coast, except for an incidental illegal landing of brown shrimp caught in the white shrimp fishery.

The management objectives of the Texas Closure regulation are designed to increase the yield of shrimp and eliminate the waste caused by discarding under-sized shrimp caught during the period of their life cycle when they are growing rapidly. The temporary closure of the offshore fishery from late May to mid-July each year has provided larger shrimp available to the fishery when fishing is again permitted beginning in mid-July. The monetary benefits of this management regulation result from catching larger, higher-priced shrimp, which increased the ex-vessel value of the fishery.

In years prior to the seasonal FCZ closure, discarding of under-sized shrimp commonly occurred because of a Texas law that prohibited fishermen from landing shrimp below a certain size, and lack of a market for small shrimp. The Texas Closure regulation, which was expected to increase the size of shrimp, therefore helped eliminate the need for discarding. The most effective method of eliminating the discarding problem was to delete the application of the Texas law to the Gulf fishery, which the state of Texas did in 1981.

The National Marine Fisheries Service annually evaluates the effectiveness of the Texas Closure by preparing a series of reports for the Gulf of Mexico Fishery Management Council. The first of these annual reports covered abundance and distribution of shrimp off the Texas coast (Matthews 31); a review of the offshore fisheries (Klima et al. 32); impacts on yield (Nichols 27); estimated impacts on the ex-vessel brown shrimp prices and values as a result of the closure (Poffenberger 28); and vessel mobility (Jones and Zweifel 33). Since the implementation of the first closure, the closure has been a success in achieving the objectives of the shrimp fishery management plan. The closure of the FCZ and the territorial sea has increased yield and value of shrimp substantially each year, \$59.5 million in 1981, with a low of \$31.7 million in 1983 (Tables 2 and 3).

TABLE 2 Summary of Commercial Catch Statistics and Resource Survey Results for Gulf of Mexico Brown Shrimp Fishery

	Year				
Statistic	1981	1982	1983	1984	1985
July–August brown shrimp catch[a]					
Texas offshore					
Catch	25.0	13.0	9.8	15.3	14.0
Effort	14.8	15.7	10.3	18.6	15.2
CPUE	1,895	922	962	819	918
Louisiana offshore					
Catch	10.5	5.1	4.9	6.6	5.5
Effort	11.9	9.8	11.2	11.2	8.6
CPUE	863	524	439	587	642
May–August brown shrimp catch[b]					
Texas					
Inshore	4.2	4.1	5.9	7.1	5.4
Offshore	25.3	13.9	10.5	16.1	14.6
Total	29.5	18.0	16.4	23.5	20.0
Louisiana					
Inshore	15.2	15.1	12.1	14.9	8.8
Offshore	23.1	13.7	8.8	13.6	16.5
Total	38.3	26.8	20.9	28.5	25.3

Source: Klima, Nichols, and Poffenberger, 1986 (62).

[a] Catch in millions of pounds, fishing effort in thousands of days, and catch per trip.

[b] Catch in millions of pounds.

Not only did the economic yield increase, but CPUE off Texas is always substantially greater during July–August than CPUE off Louisiana (Tables 2 and 3). Small emigrating brown shrimp are protected and allowed to grow to a larger size. Discarding was a problem only in 1985 when unusual biological conditions prevailed resulting in smaller shrimp at the opening of the season, and approximately 1.1 million lb was discarded immediately after the area was open to fishing.

Without the prohibition on trawling during the period of brown shrimp emigration, it is believed that large quantities of small brown shrimp would have been caught resulting in wastage and lower yield to the fishery both biologically and economically (Klima et al. 13). That is not to say there are no problems associated with the Texas Closure; quite the contrary, there are several problems that cause concern not only for Texas shrimpers, but shrimpers from other Gulf coastal states. These are as follows:

1. Loss of migrating shrimp to Mexico occurs during the closure period.

TABLE 3 Summary of Analytical Results of Texas Closure Shrimp Fishery Management Measure, 1981–1985[a]

	Year				
Statistic	1981	1982	1983	1984	1985
FCZ Closure					
CPUE ratio Texas: elsewhere[b]					
July	2.26	2.06	2.34	1.86	1.69
August	1.56	1.35	1.40	1.34	0.95
Increase in Y/R at $F = 1.0$ ($M = 0.15$–0.28)	+14 to +37%	−10 to +10%	+12 to +33%	+15 to +33%	+14 to +33%
Change in Gulfwide yield (million pounds)					
May–August	+4.0 (5%)	+0.7 (1%)	−0.5 (1%)	−0.6 (1%)	−0.8 (1%)
May–April	+4.2 (4%)	+1.4 (2%)	+0.4 (1%)	+1.4 (2%)	[c]
Change in Gulfwide value (million dollars)					
May–August	+10.4 (7%)	+5.3 (3%)	+2.1 (2%)	+8.5 (6%)	+0.8 (1%)
May–April	+9.7 (4%)	+6.0 (3%)	+6.7 (3%)	18.7 (9%)	[c]
Combined closures (FCZ and territorial sea)					
Change in Gulfwide yield					
May–April (million pounds)	+9.8 (10%)	+4.9 (7%)	+3.5 (6%)	+5.1 (6%)	[c]
Change in Gulfwide value					
May–April (million dollars)	+59.5 (25%)	+43.2 (19%)	+31.7 (16%)	+37.4 (18%)	[c]

[a] Values shown are the statistics used to measure the effects of the closure for the Fishery Conservation Zone (FCZ) alone and for the territorial sea and FCZ combined.

[b] Long-term average CPUE ratios (Texas: elsewhere) for 1960–1980 are July, 1.27; August, 1.06.

[c] Data required for estimate not yet available.

Y/R = Yield per recruit.

Source: Klima, Nichols and Poffenberger, 1986 (62).

2. Too many vessels fishing off Texas during the open season leave few shrimp for the resident vessels during the remainder of the fishing season and cause a concentration of vessels at the opening.
3. Increasing inshore shrimp fisheries harvest small juvenile shrimp, thereby reducing the potential yield to the offshore fishery.
4. Closure is not consistently applied throughout the northern Gulf.
5. Lower prices have been paid to the fishermen during July and August since 1984.
6. Tie up of vessels occurs during the closure and illegal fishing in Mexico, and high cost and long distance to fish off Louisiana.

The loss of migrating shrimp to Mexican waters, where U.S. fishermen are prohibited from fishing, does cause concern to U.S. fishermen. A major study is underway to define this loss rate, but data from 1978 to 1980 do not show a significant loss of shrimp from the United States into Mexico (Klima et al. 10).

Local Texas fishermen have complained seriously about the concentration of vessels off the Texas coast at the opening of the Texas shrimp season. Many of these vessels are from other parts of the Gulf with the resulting concentration of vessels causing problems at the opening of the fishing season. If catch rates are high, discarding increases because of the crews' inability to handle and sort the shrimp before the next tow. Poorer-quality shrimp may also be associated with high catch rates and inferior handling at the opening. Pulse fishing and an increased fishing effort at the beginning of the season opening are postulated to have an impact on individual fishermen by decreasing the yield per individual fisherman (Nichols 33a). If fishing effort is increased by 12–25%, decreases in yield per individual fisherman are noted; however, no decrease in value would be observed until fishing effort increased by 45%.

The total number of vessels fishing in the Gulf of Mexico has not drastically increased since 1976, when approximately 4177 vessels operated. In 1983, a total of 4999 vessels was operating in the Gulf of Mexico; an increase of only 16%. The increase in gear efficiency is more devastating. In 1976 less than 5% of the offshore vessels were quad-rigged, whereas in 1985 probably more than 60% were quad-rigged (four nets). A quad-rigged vessel sweeps twice the bottom area of a double-rigged vessel and at least four times the bottom area of a single-rig vessel. This indicates a substantial increase in the efficiency or fishing power of the Gulf fleet of offshore vessels. Although there is only a small increase in the number of vessels (i.e., 16%), the dragging efficiency is almost 75% greater than in 1976, and a total increase in fishing potential of 91%. Because total catch has remained the same there is more capacity than is needed to harvest the shrimp resources of the Gulf of Mexico. This overcapacity is one of the root problems of the shrimp fishery.

Nichols (34) has also shown that an increase in inshore fishing can have a marked impact on the offshore fleet. A decrease of 50% in inshore fishing effort increases offshore poundage yields by approximately 56%. Contrarily, a doubling of inshore effort reduces offshore yields by 59%. He further showed that offshore yields are less responsive to an increase in fishing mortality. A doubling of offshore fishing would decrease offshore yields by 28%. Nichols (34) has also shown that offshore yield-per-recruit in dollars is more responsive to changes in inshore fishing, but not to changes in offshore fishing. A doubling of inshore fishing mortality would decrease offshore dollar yields per recruit by 59%, and total yield-per-recruit in dollars would decrease 31% with a 100% increase in inshore fishing at present levels. A decrease of 50% in inshore fishing would increase total yield per recruit in dollars by 25%. A doubling of offshore fishing mortality would increase total dollar yield only by 4%. Klima et al. (13) pointed out that inshore landings were very similar in 1981, 1982, 1983, and 1984, despite evidence of considerably lower recruitment in some years, and that the increasing inshore fisheries in Texas may soon begin to have an impact on offshore yields.

The economic condition of the shrimp fishery has changed since the late 1970's. Vessel numbers have increased slightly, fishing power has doubled, access to Mexican fishing grounds has been stopped, insurance premiums have increased 300%, and the ex-vessel price paid for shrimp is lower than indexes of other food products. The overcapacity and excess fishing power of the fleet in the Gulf of Mexico, the increasing landings of small shrimp by the inshore fisheries in the northern Gulf, and the changing economic condition of the fishery are major problems and appear to be the main factors causing economic hardship on U.S. fishermen. Poffenberger (35) has shown that the price structure paid for shrimp during July and August is not directly impacted by opening of the season, but by other factors such as the imports of shrimp into the United States. The combination of poor recruitment during 1982–1985, no closure of other areas in the northern Gulf, overcapacity of the fleet, increased inshore fisheries, and perceptions by fishermen of lack of enforcement and loss of migrating shrimp to Mexico have caused serious concern related to the Texas Closure. As a result, in January 1986 at the GMFMC meeting the Council voted to suspend the Texas Closure for 1 year.

A lack of a Gulfwide closure similar to the one off Texas is perceived by many fishermen to hold potential for some financial gains. Nichols (36) has shown that a delay until June 1 in the harvesting of the extremely small shrimp (> 100 count) found in the bays and estuaries of Louisiana and Texas would significantly increase shrimp yield. Klima et al. (13) have pointed out that shrimp of at least 100 count or larger are harvested in May and June throughout Louisiana and Texas inshore areas. Optimum size of harvest for brown shrimp is somewhere between 40 and 50 count (Nichols 11). Therefore, any management measure that restricts harvesting of small shrimp should substantially increase the gain in both pounds and dollars to the fishermen.

A Gulfwide closure would decrease the possibility of pulse fishing and increase the potential for additional revenues from the brown shrimp stock. Such a closure is unlikely in the immediate future because Louisiana, Mississippi, and Alabama regulations are geared for social and economic goals and therefore the need for small shrimp is prevalent in these areas in order to maintain high employment levels in both fishing and processing sectors. Therefore, the likelihood of anticipating a closure in other areas of the Gulf of Mexico is low.

3.3. Research and Management

A current major cooperative program in the Gulf of Mexico is SEAMAP, in which the various coastal states participate with the federal government in sampling both offshore and nearshore areas throughout the Gulf of Mexico (Bane 37). Sampling is concentrated in three areas: demersal finfish and shrimp, ichthyoplankton, and environmental information. Surveys are conducted at various times of the year utilizing both federal and state research vessels in a cooperative effort to minimize duplication and cut costs. Data are shared between the states and the federal agencies. Plans for these surveys are formulated by SEAMAP working groups under the auspices of the Gulf States Marine Fisheries Commission. Data from these surveys have been used to evaluate the Texas Closure (Nichols 27; and Matthews 31) and are useful in assessements of king mackerel and Spanish mackerel, also under federal regulation. The information obtained can be used by any of the partners involved in the SEAMAP investigation.

4. ESTUARIES

The Gulf of Mexico estuaries serve as nurseries, providing protection and food for shrimp, menhaden, flounder, spot, croaker, spotted seatrout, redfish, oysters, and a host of other important organisms. Many of these species spawn in offshore waters and their young stages are swept into the bays, bayous, and tributaries by currents. They utilize shallow portions of salt marshes, mangrove, and seagrass areas to grow and be protected from predators (Zimmerman and Minello 38). As juveniles, they utilize the open bays where they are first exposed to fishing pressures and then migrate to offshore waters.

Human population growth in the southeast coastal regions of the United States is substantially greater than the national average and is accompanied by industrial and real estate development. Alteration or destruction of 1% of estuarine habitats required by commercial and recreational fishery species occurs each year. Louisiana marshes are vanishing at the rate of approximately 50 square miles annually (Gaglian et al. 39; Hatton et al. 40; Baumann et al. 41). Sea level is expected to rise substantially (Titus and Barth 42), compounding the loss of critical estuarine areas in the Gulf of Mexico. The freshwater demand for industrial and urban uses in Texas has increased from 2 million acre-ft in 1930 to about 17.9 million acre-ft in 1980 and is expected to increase with the projected expanding population growth. The increased use of freshwater will limit inflows into Texas bays and impact their productivity.

Highly productive estuarine areas are presently being dramatically altered by

humans. The economic value and demand for nearshore property has increased rapidly in recent years. Sustained production of marine fisheries is strongly linked to maintenance of nearshore habitats, and the protection, management, and restoration of these habitats is a critical fisheries issue. The maintenance of important fishery habitats is the responsibility of both state and federal governments, and NOAA/NMFS is taking a leading role because fish do not recognize political boundaries.

As part of its responsibility, NMFS makes recommendations to the U.S. Army Corps of Engineers on permit applications that modify estuarine habitats. The National Marine Fisheries Service began quantifying the cumulative acreage or habitat in the Corps of Engineers permit program in 1981 in the southeast region. Habitat preserved as a result of these recommendations in 1981 alone was estimated to be worth more than $33 million to the commercial and recreational fishing industry (Lindall and Thayer 43). However, these recommendations are based heavily on available information concerning relationships between habitat and fishery production. All too often the information base is not sufficient to allow informed decisions on the impacts of chemical and physical alterations. As a result, the agency and others are forced into a holding action to slow changes until the necessary information can be developed. In the meantime, changes do occur and habitat is eroded or lost.

The shrimp fishery of the Gulf of Mexico has been studied intensively, and the available information may be adequate for maintenance of the fishable stocks if current conditions remain the same. But conditions are changing and information is not adequate for understanding functional relationships and impacts of various habitat alterations on the survival, growth, and distribution of the juveniles in the estuaries or the adults offshore (Fig. 12).

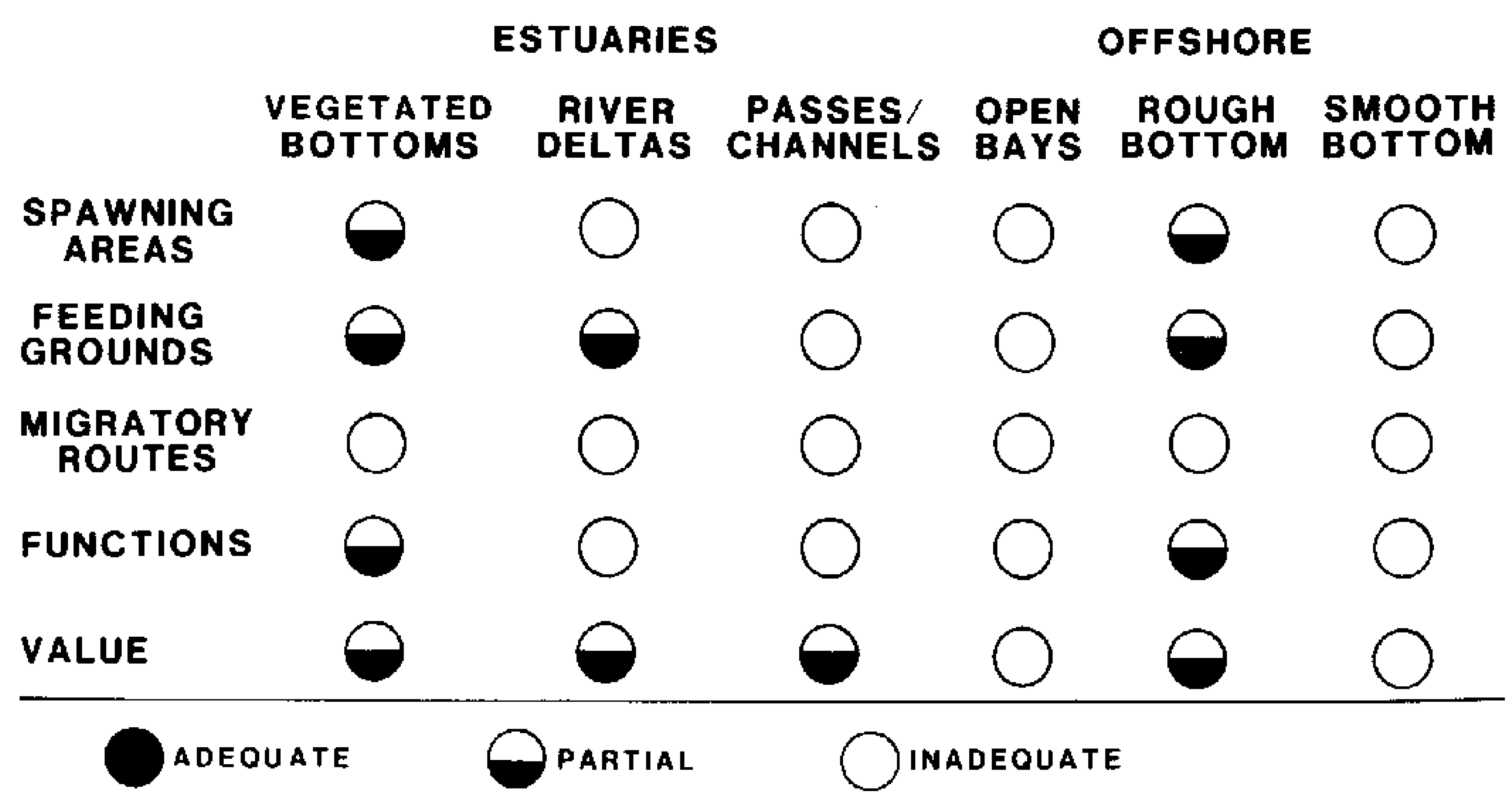

Figure 12. Status of habitat information on shrimp.

5. RESEARCH

Shrimp research has been directed at monitoring landings and evaluating management measures designed to increase yield by allowing more time for shrimp to grow before they are caught. Unfortunately, limited research has been conducted on factors that affect recruitment. Some understanding exists on general environmental conditions that influence survival of young in estuarine nurseries, but this understanding is inadequate either for predicting yield or for understanding environmental impacts such as alteration of freshwater inflow and destruction of estuarine habitat. The information is inadequate to quantify the value of habitats within estuarine systems for shrimp production. Such information will be extremely important in terms of offsetting damage or alterations to the environment.

Temperature and salinity are the two most important factors controlling survival and growth of young shrimp (Zein-Eldin and Aldrich 44; Aldrich et al. 45). However, there are obviously other factors that are important as well. Renaud (46) has shown hypoxia (less than 2.0 ppm dissolved oxygen) off the coast of Louisiana affects the distribution of penaeid shrimp. Zimmerman et al. (47) and Minello and Zimmerman (48–50) have shown that vegetated habitat and predation affect the abundance of juvenile penaeids. Cause–effect relationships and interactions between variables such as temperature, salinity, substrate availability, predation, precipitation, river discharge, and habitat type are not known for any of the penaeids at this time. Zein-Eldin and Renaud (51) noted a lack of information necessary to protect and even enhance the habitat for penaeid shrimp. Temperature and salinity have been shown to be correlated with brown shrimp harvest in some areas. Matylewich and Mundy (52), Barrett and Gillespie (53) and Barrett and Ralph (54) have shown that poor catches of brown shrimp in the spring are associated with heavy precipitation and low water temperatures in Louisiana. The use of environmental variables to predict future harvest varies from region to region and from state to state. Sutter and Christmas (55) used multiple regression analysis including water temperature, salinity, and the number of postlarval brown shrimp in nursery areas to predict the June–July commercial harvest in Mississippi waters. Klima et al. (32) used catch of shrimp by the bait shrimp fishery of Galveston Bay to predict annual offshore harvest of brown shrimp from Texas waters. Standing stock of juvenile shrimp in estuaries and postlarval abundance indexes have also been used to predict annual Texas offshore catches of brown shrimp (Sullivan et al. 56; and Baxter 57).

Forecasting shrimp production is in its infancy. Generally, some reasonable forecasts can be made for brown shrimp; however, this is not true for white or pink shrimp stocks. Environmental parameters are useful in forecasting if extreme conditions are observed but forecasts are not accurate under average environmental conditions. In contrast, bait shrimp indexes of juvenile abundances based on line bait catches are better for forecasting in average years than in extremely poor or excellent years.

Direct exploitation of intertidal habitats by fishery organisms in the Gulf of

Mexico may be more important than previously thought. Juveniles of commercial species such as brown shrimp, spotted seatrout (*Cynoscion nebulosus*), and southern flounder (*Paralichthys lethostigma*) have been shown to invade intertidal marsh habitat in preference to subtidal open water (Zimmerman and Minello 38). Because direct exploitation of intertidal areas depends on inundation, tidal dynamics are important in controlling accessibility for these organisms to preferred habitat. In the Gulf of Mexico, seasonal tides dominate daily tides (Provost 58), resulting in higher and longer inundation events on the Gulf coast during the spring and fall (Hicks et al. 59). Historical postlarval recruitment of brown shrimp coincides with these spring and fall high tides, suggesting a relationship and perhaps dependency on access to marsh habitats (Zimmerman et al. 47). Brown shrimp may benefit additionally where marshes are lower owing to sea level rises and local land subsidence. The northwestern Gulf of Mexico has one of the highest rates of apparent sea-level rise of all U.S. coastal regions (Hicks et al. 59), and one consequence is increased flooding of cordgrass (*Spartina alterniflora* and *S. patens*) marshes. This flooding increases the area and duration of accessibility to optimal habitat for brown shrimp, and may result in higher production.

Such production appears to be related to increased food supply. Growth rates of brown shrimp are higher in *S. alterniflora* habitat than in open water (Zimmerman and Minello 60). Higher growth rates are apparently caused by greater abundances of food organisms (pericarid crustaceans and polychaete worms) in *Spartina* habitat.

Zimmerman and Minello (61) suggest that food abundance and temperature are primary factors controlling growth, but neither affect mortality except under extreme conditions. Survival of postlarval and juvenile shrimp in salt marsh nurseries appears to be largely regulated by predation. Estimates of juvenile brown shrimp (11–40 mm total length) mortality in a Galveston Bay salt marsh have been made from an examination of size-frequency distributions, and actual mortality during spring months ranged from 43 to 70% over a 2-week period. In field experiments, where fish predators were excluded from experimental enclosures, brown shrimp mortality over a similar length of time was only 3–11%. Studies of stomach contents indicate that the dominant fish predator on shrimp in the marsh during the spring months is the southern flounder, (*Paralichthys lethostigma*). During the late summer and fall, red drum, (*Scianenops ocellatus*), and spotted seatrout, (*Cynoscion nebulosus*), feed on juvenile shrimp.

The presence of emergent marsh vegetation reduces fish predation on juvenile brown shrimp (Minello and Zimmerman 48; Zimmerman and Minello 60), but does not appear to protect white shrimp, (*Penaeus setiferus*), in a similar manner (Minello and Zimmerman 50). Other characteristics of nursery habitats that protect brown shrimp from at least some predators include turbid water and a suitable substrate for burrowing by shrimp (Minello and Zimmerman 49). Continued research in these areas will provide information needed to model mortality of shrimp. Shrimp mortality can be affected by predator and prey density, predator and prey size, density of alternative prey, the presence of various habitat characteristics, physical and chemical variables, and interactions among many factors. The model could be useful for predicting survival of shrimp under various conditions and for determining the most important protective habitats for juvenile shrimp.

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